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EFFECT OF DIFFERENT PACKAGING SYSTEMS ON QUALITY AND SHELF-LIFE OF TWO SWEET PEPPER (*Capsicum annuum var grossum)* VARIETIES DURING STORAGE AT ROOM TEMPERATURE.

BY

JOSEPH YAW AFRIYIE

MAY, 2013

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A THESIS SUBMITTED TO THE SCHOOL OF RESEARCH AND GRADUATE STUDIES, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE (MSc. POSTHARVEST TECHNOLOGY) DEGREE.

BY

JOSEPH YAW AFRIYIE

MAY, 2013

DECLARATION

I hereby declare that, except for specific references which have been duly acknowledged, this project is the result of my own research and it has not been submitted either in part or whole for any other degree elsewhere.

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DEDICATIONS

To the Glory of God, I dedicate this work to my dear mother, Madam Grace Donkor, whose loving concern has made my education a reality.

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ABSTRACT

An experiment was conducted to assess the effects of different packaging systems on quality and shelf-life of two sweet pepper (*Capsicum annuum)* varieties during storage at room temperature. The field work was carried out at Berekum College of Education in the Brong-Ahafo Region and the laboratory work was conducted at the Department of Horticulture, Kwame Nkrumah University of Science and Technology, Kumasi in February to March, 2012. Physiologically mature green fruits uniform in size was used. A 2x5 factorial in Completely Randomised Design (CRD) with three replications was used for the study. The treatments consisted of two sweet pepper varieties and five packaging systems. From the results, weight loss was significantly lowest in both perforated (29.99%) and un-perforated (25.05%) polyethylene bag. Yolo Wonder variety was significantly higher in total soluble solids (6.70°Brix) than California Wonder variety (5.93°Brix). Wooden box and unpackaged fruits had significantly higher TSS of 7.24°Brix and 8.41°Brix respectively. California Wonder had significantly higher moisture content (92.31%) whiles Yolo Wonder had significantly higher dry matter content. Un-perforated polyethylene package had significantly higher moisture content (94.36%) but lower dry matter content (5.64). Wooden box had a high dry matter content of 10.24.The polyethylene bags retain skin green colour better than the wooden box, jute sack and unpackaged fruits. However, packaging did not significantly affect colour retention. Un-perforated polyethylene bag recorded the highest decay fruits (35%) and the lowest shrivelled fruits (28.33%). Wooden box and unpackaged fruits had no decay fruits but unpackaged fruits recorded the highest shrivelled fruits (83.33%). Un-perforated polyethylene bag had the longest shelf-life of 20 days. In conclusion, for

longer shelf-life and better quality, storing both California Wonder and Yolo Wonder in unperforated low density polyethylene bag should not be extended beyond the twentieth day as majority of the fruits started decaying.

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CHAPTER ONE

INTRODUCTION

Food is essential to man's survival; therefore, it is necessary that great attention is paid to food production, distribution, wholesomeness and preservation (Ihekoronye and Ngoddy, 1985).

All through history, man has been striving to increase his food production to match population growth. This has led to much pressure on development in agricultural technologies which has caused substantial increases in world food production (Salunka*et al*., 1991).

Sweet pepper is frequently grown as backyard garden crop and in market gardens near cities and urban areas in Ghana (Tweneboah, 1997). It is a source of employment and income to both rural and urban dwellers. It contributes significantly to the economic growth of the country and is a source of foreign exchange (FAO, 2006).

Peppers are the second most important crop among the *Solanaceous* fruits. From the point of view of nutrients obtained from these crops, peppers are by far superior to both tomato and egg plant in vitamins A and C content (Yamaguchi, 1983).

One major constraint confronting sweet pepper production in developing countries is post – harvest losses as a result of unavailability of storage facilitie (Anon, 2003). It deteriorates rapidly during storage and poor post – harvest handling leading to huge losses (Gorini *et al*., 1977).

Most local growers and produce handlers keep the perishables at ambient condition under which the quality of sweet pepper can be maintained for only a short time (3 – 4 days); while at the optimum storage temperature of 7°C to 10°C and about 90 percent relative humidity, they can store for fourteen days (Yamaguchi, 1983).

The purpose of post – harvest handling system is to deliver appealing and nutritious food to consumers in an economic manner. Handlers and consumers therefore attach a lot of importance to the retention of fruit green colour, freshness and firmness as quality attributes during handling and storage. In addition, absence of defects, diseases, as well as shelf – life is also considered. These quality parameters are functions of temperature, relative humidity and air composition of handling or storage environment (Jobling, 2001).

Cold storage of fruits on large scale is not common in most developing countries like Ghana, due to the cost involved. Fruits are kept in ambient environment where temperature is often high with fluctuating relative humidity (Esquerra and Bautista, 1990). Fruits stored under this condition loose moisture rapidly leading to deterioration and ripening.

Modified atmospheres are designed to slow down respiration and thus senescence by reducing oxygen or increasing carbon dioxide concentration (Kader, 1985). Therefore, there is a need to understand the interaction among the many operations necessary for delivering sweet pepper to consumers in order to predict their impact on produce quality. Pre – packaging and storage of sweet pepper at ambient conditions are commonly practiced by growers and handlers but their potential in maintaining produce quality is not well understood.

Determining the best pre-packaging material for sweet pepper may assist growers, dealers and consumers in maintaining quality of sweet pepper. It is therefore important to evaluate the effect of different packaging materials on quality and shelf–life of two cultivars of sweet pepper.

The objectives of the study therefore were to:

1. assess the effect of low density perforated and non – perforated polyethylene bags on quality and shelf – life of sweet pepper; and
2. evaluate the effect of transparent (low density polyethylene bags) and non–transparent (wooden box and jute sack) packages on quality and shelf-life of sweet pepper.

CHAPTER TWO

LITERATURE REVIEW

2.1 ORIGIN AND BOTANY

Sweet pepper *(capsicum annuum*), also known as mild bell pepper originated and was domesticated in central America, probably in Mexico, where archaeological digs have revealed that it was already used by man around 7,000BC (Grubben and Denton, 2004). It was introduced into Europe towards the end of the 15th Century by the Spanish and Portuguese explorers; it's cultivation later spread to Africa (Tindall, 1988).

Capsicum annuum is a herbaceous annual that belongs to the family *solannaceae*. The erect, branching stems may attain a height of 50 – 80cm. the leaves are glabrous and often lanceolate. When grown in deep, homogeneous soils, it develops a root system that may extend to a depth of between 40 and 70 cm (Raemaekers, 2001).

Sweet pepper is an autogamous species but the level of cross – pollination varies from 2% to 40%, depending on insect activity. It bears solitary white flowers which appear at each node. The peduncle is pendulous at anthesis (Amati *et al*., 1995).

The fruit is a hollow berry with 3 or 4 loculi whose septa do not extend to the center. It may be elongated or rounded and ribbed. It is usually green in colour, but may turn yellow or red on maturity (Tweneboah, 1997).

Among the cultivars of sweet pepper include Big Bertha, California Wonder, Yolo Wonder, North Star, Lady Bell, Jupiter and Bell Boy. The Yolo Wonder is a 4–square, 3-4 lobed pepper. The highly glossy fruits are an improved California wonder (Raemaekers, 2001).

2.1.1 Importance of Sweet Pepper

Capsicum fruits are consumed in fresh, dried or processed form. Non – pungent fruits are eaten raw in salads, but more commonly cooked, fried or processed together with other foods. They are consumed in such quantity per serving that they constitute a real table vegetable contributing to the nutritional value of the meal (Grubben and Denton, 2004).

2.1.2 Nutritional Composition of Sweet Pepper

One hundred grams of the edible part of sweet pepper (approximately 87% of the total weight of the fruit) contain 92g water, 1.3g protein, 10.3g carbohydrate (including 1.4g cellulose), 12mg calcium, 0.9mg iron, 1.8mg carotene, 0.007mg thiamine, 0.08riboflavin, 0.8mg niacin and 103mg vitamin C (Raemaekers, 2001).

2.2 GROWTH REQUIREMENT OF SWEET PEPPER

Sweet pepper has almost the same climate requirement as eggplant *(Solanum melongena)* and tomato (*Lycopersicon esculentum*). Although, the pepper plant may withstand a lower temperature range, the plant grows well in a relatively warm climatic condition, where the growing season is long (Amati *et al*., 1995).

2.2.1 Soil

Capsicum annuum can be grown in a variety of soils but the plant prefers friable, deep sandy loams which are well – drained and rich in organic matter. It is not generally sensitive to soil acidity. Thus the plant is fairly tolerant to acid soils, hence liming is unnecessary, unless pH is less than 5.0. However, an optimum pH of 5.0 – 7.0 is good for its proper growth (Raemaekers, 2001).

2.2.2 Rainfall and Temperature

Sweet pepper requires a rainfall of 600mm – 1200mm per annum, if grown as rainfed, but an optimum of 750mm per annum is appreciable. A lower humidity and high temperature (above 30°c) can cause abscission of the buds and flowers, as well as the development of small fruits (Tweneboah, 1997).According to Messiaen (1995), irrigation should be regular and regulated, especially during the dry season to avoid soil water deficit. In contrast, excessive irrigation should be avoided, since root system is particularly sensitive to water logging.

2.2.3 Fertilizer Application

Sweet pepper requires 350kg of NPK 15-15-15 fertilizer per hectare to produce a good crop. The fertilizer should be applied as a split dose; the first – half is applied 10days after transplanting and the second half 10days after the first application (Tweneboah, 1997).According to Tindall (1988), sweet pepper is an early crop with some cultivars flowering in about 40 days from the time of sowing the seeds. Thus if fertilizer application is not done at the correct stage of growth, yields will be reduced. Care should be exercised to avoid the application of excess nitrogen because it promotes vegetative growth at the expense of yield. If the crop shows signs of luxuriant growth after the first fertilizer application, the second application should not be carried out (Amati *et al.*, 1995).

2.2.4 Flowering and Fruit Set

Sweet pepper is an early crop with some cultivars flowering in about 40days from the time of sowing the seeds. The flowers are borne single in the leaf axils, and when mature the fruits are generally big, with some up to 30cm long of variable shapes (Tweneboah, 1997). Fruit set is an important aspect in crop production when considering yield. Temperature has been found to be an important determinant in the fruit set. Studies have shown that anthesis completes by 8.00am and most flowers shed their pollen by 9:00am (Raemaekers, 2001). Pollination on the day of opening results in maximum fruit set. Some *capsicum* trials indicated that at the start of flowering, about 50 – 75% of the flowers set fruit but later this rate decreases progressively until it stops and then starts all over again (Grubben and Denton, 2004).

2.2.5 Harvesting

Harvesting begins approximately 60 to 80 days after transplanting and may extend over a period of 30 to 70 days. Depending on the cultivar, the fruits may be gathered before they mature (green) or when they are fully riped (red or yellow). The cultivars ‘‘Yolo and California wonders’’ are usually harvested when the fruits are 10 – 12cm in length and have a diameter of 8 – 10cm (Amati *et al.*, 1995).

2.2.6 Pests and Diseases

Pests and diseases are important environmental factors that affect the growth and yield, as well as market quality of crops (Messiaen, 1995). A number of insect pests affect pepper, thus, the crop becomes prone to diseases that result in poor quality of pepper production. The cost of production is also increased by the occurrence of insect pests, and this can be shown by the extra cost involved in controlling pests on the field. Among the insect pests that attack pepper plants include Thrips, Aphids, Cotton stainer, variegated grasshopper and white fly. (Mathew and Karikari, 1990; Tindall, 1988).

According to Tweneboah (1997), diseases of sweet pepper include Fusarium wilt, Pepper mottle virus and Powdery mildew. Others include fruit rot, leaf spot and nematodes which sometimes cause serious damage to the crop. Root– knot nematode retards the growth of pepper. In most cases, this results into death of plants (Amati *et al.*, 1995).

2.3 FRUIT RIPENING

Ripening is a critical transitional period from maturation to senescence in fruits. It involves changes in sensory factors like colour, texture, taste and flavor which render the fruit acceptable to the consumer (Wills *et al.,* 1989). Some of these changes may be detected by observation or analysis of pigment, pectin, carbohydrates, acids and tannins. Other changes associated with ripening include abscission, respiration rate, rate of ethylene production, tissue permeability, softening (Changes in the composition of pectic substances), carbohydrate composition, organic acids and development of wax on skin among others (wills *et al*., 1989). Therefore, to ensure quality and increased storage life of products, modified atmosphere storage is employed to lower the rate of these biochemical processes associated with ripening.

2.4 MODIFIED ATMOSPHERE STORAGE OF FRUITS AND VEGETBALES

The basic principle of modified atmosphere storage is the imposition of an abnormal external environment for the purpose of lowering the rate of internal, biochemical processes which are associated with ripening and senescence. These processes if not checked early enough, normally, reduce the edibility or desirability of stored products (Smith *et al*., 1988).

Some of the biochemical processes associated with ripening of fruits include changes in respiration rate, changes in rate of ethylene production, softening (changes in composition of pectin substances), variation in carbohydrate composition and changes in fruit colour among others (wills *et al*., 1989).

Attempts should, therefore, be made to study modified atmosphere storage in detail and also the influence of modified atmosphere storage on some of these biochemical processes associated with quality and shelf-life of storage products.

2.4.1 Composition of Storage Atmosphere

The composition of gas in the storage atmosphere affects the storage life of products. Alteration in the concentration of respiratory gas, oxygen and carbon dioxide may extend storage life of such products (smith *et al*., 1988).

The manipulation of the natural composition of air in the storage atmosphere can be achieved through modified atmosphere storage, vacuum packaging, controlled atmosphere storage, and the use of oxygen absorbent or gas generator (Wills *et al*., 1989). With modified atmosphere storage, the products are kept in a good barrier material in which the gaseous environment has been changed (Fellows and Axtell, 1993). This is done to slow down respiratory rates, reduce microbiological growth and retard enzymatic spoilage with the final effect of lengthening shelf-life of the products (Thompson, 1996). Wills *et al,*. (1989) noted that with modified atmosphere storage, where the storage atmosphere is not closely controlled, the changes in the storage atmosphere are brought about by the respiring products.

Controlled atmosphere storage generally decreases oxygen and increases carbon dioxide levels in the storage environment in precise concentration (wills *et al*., 1989). Vacuum packaging is strictly a form of modified atmosphere where the products are placed in high barrier package from which air is removed to prevent growth of aerobic spoilage organisms, shrinkage, oxidation and colour deterioration (Jobling, 2001).

The use of oxygen absorber is another way in which the storage atmosphere can be modified. The oxygen absorbers are defined as a range of chemical compounds introduced into storage package (not on the product) to alter the atmosphere within the package. These compounds remove oxygen or add carbon dioxide into the package environment. Oxygen absorbers in general act as a compliment to modified atmospheres storage by reducing oxygen levels (Kader, 1985).

2.4.2 Factors Affecting Quality and Shelf- life of Modified Atmosphere Products

2.4.2.1 Gaseous environment

Carbon dioxide is found in the atmosphere in trace amount (around 0.03 percent) and is a by–product of respiration. Its effect on microorganism varies with the types of organism. Some require small amount of carbon dioxide while others are inhibited or killed in its presence (Wills *et al.*, 1989). Carbon dioxide is important because of its activity against many spoilage organisms which grow at refrigeration temperature. To be effective, carbon dioxide must be applied at relatively high concentration and to ensure its availability for extended period of time (Kader, 1985).

The mechanism of inhibition is not known, but it is speculated that inhibition may be due to a simple lowering of pH within the cells of some organisms or it may inhibit specific metabolic pathways (Thompson, 1996). Carbon dioxide has the advantage of being relatively non–toxic to humans; however, if the concentration of carbon dioxide is too high, it may results in discolouration and a sharp acid taste in products (Ellis, 1993). Oxygen forms about 21 percent of the air composition and it is known for its reactivity. Oxygen inhibits the growth of anaerobic pathogen; therefore, its inclusion in a package can be a safety factor. But on the other hand, most spoilage micro – organisms require oxygen and therefore, it exclusion makes sense from the stand point of spoilage since much deterioration of flavor and colour, oxidation and also mould growth may proceed even in the presence of small amount of residual oxygen (Harima, 1990).

2.4.2.2 Packaging material

The material used for packaging must adhere to certain criteria such as having low vapour transmission rates and preventing changes in moisture content. Therefore, for the selection of packaging material, certain factors should be taken into consideration such as the gas and moisture barrier properties, adequate strength, absence of damaging corners or surfaces and mechanical injury (Ellis, 1993).

A good packaging according to Ellis (1993) enhances saleability of the goods, being itself attractive, displaying label and contents to advantage, and being of suitable size as a unit of sale. It also gives protection from dirt, dust and infection. On the other hand by keeping humidity high, it may favour disease causing organism in stored products.

2.4.3 Types of Packaging Materials Used in Modified Atmosphere Storage

2.4.3.1 Wood

Wood containers have traditionally been used for a wide range of solid and liquid foods including fruits, vegetables, tea and beer. Wood offers good mechanical protection, good stacking characteristics and a high weigh–to–strength ratio. However, plastic containers have a lower cost and have largely replaced wood in many applications. Wooden crates are made for transporting fresh fruit and vegetables, fish etc. they are used to hold foods together and protects them from crushing (Ellis, 1993).

2.4.3.2 Plastic

This is the most common packaging material and, at the same time, one of the most difficult to dispose of. The factors common to all plastics are that they are light, strong and cheap to manufacture. It is for these reasons that they are used so much, as an alternative to other packaging materials. Among the plastic films are cellulose, polypropylene and polyethylene (low and high density) (Meir *et al.*, 1983).

Low – density polyethylene is heat sealable, inert, odour free and shrinks when heated. It is a good moisture barrier but has relatively high gas permeability. It is less expensive than most films and is therefore widely used. High – density polyethylene is stronger, thicker, less flexible and more brittle than low – density polyethylene and has lower permeability to gases and moisture. It has higher softening temperature (121°c) and can therefore be heat sterilized. Bags made from 0.03 – 0.15mm high – densityPolyethylene have high tear strength, penetration resistance and seal strength. They are water proof and chemically resistant and are used instead of paper bags (Lisboa *et al*.,1983).

2.4.3.3 Textiles

Textile containers have poor gas and moisture barrier properties and have a poorer appearance than plastic (Esquerra, E. B. And Bautista, 1990).

2.4.3.4 Cotton

Calico is usually a closely woven, strong, plain, cotton fabric which is inexpensive and is satisfactory as a wrapper for flour, grains, legumes, coffee beans and powdered or granulated sugar. It can be re–used as many times as the material withstands washing and is easily marked to indicate the contents of the bag (Aharoni *et al*., 2007).

2.4.3.5 Jute sack bag

Jute sack bag is popular and environmental friendly packaging solution for agricultural industry. Jute sack bag also called jute hydro carbon bag which is specially made from agro-based product has no contamination of hydrocarbons and it is completely free from kerosene smell. Woven jute sacks, which are chemically treated to proven rotting and to reduce their flammability, are non– slip, have a high tear resistance, and good durability. They are used to store and transport a wide variety of bulk foods including vegetables, grain, flour, sugar and salt (Ellis, 1993).

2.4.3.6 Glass

An ideal material for foods, especially liquids. It is inalterable, strong and easy to recycle. It is the traditional vessel in the home (jars, glasses, jugs etc). Its weight and shape may involve some difficulties for transport and storage (Wills, *et al.*,1989).

2.5 EFFECT OF MODIFIED ATMOSPHERE STORAGE ON PHYSIOLOGICAL CHANGES IN FRUITS AND VEGETABLES

2.5.1 Respiration Rate of Fruits and Vegetables

Some fruits exhibit climacteric respiration, which is an upsurge in respiration that occurs at the end of the maturation phase and proceeds to breakdown or senescence. Fruits which do not show great change in respiration rate during ripening fall into the non – climacteric class (Wills *et al*, 1989).

Baile (1964) found out that the commencement of the respiration climacteric concide approximately with the attainment of the maximum fruit size. The auther also noted that all other changes or characteristics of ripening occur during the climacteric period. Therefore, the longer the period before climacteric in the storage life of a product, the longer the shelf-life of the product. However, increase in carbon dioxide and decrease in oxygen concentrations in the storage environment of products as in modified atmosphere storage, exert largely independent effect on respiration and other metabolic reactions (Kays, 1991). Pre–climacteric period has been noted to have increased to about three fold in bananas when they were stored in an atmosphere enriched with Carbon dioxide (Baile and Young, 1981). It should, however be noted that, if carbon dioxide levels are too high, it will lead to a condition when the fruit becomes discoloured and acidic (Esquerra and Bautista, 1990).

Responses to increase carbon dioxide levels vary widely among products. For instance, cherries and straw berries will withstand, or even benefit from exposure to 30percent carbon dioxide for short period. Some apple cultivars are injured by 6 percent carbon dioxide in storage. Egg plants and green peas can tolerate levels of carbon dioxide up to 7 percent in storage at room temperature (Kader and Morris, 1977). Climacteric respiration is also influenced by species, state of maturity and storage temperature of products (Wills *et al.*, 1989).

2.5.2 Colour Retention in Fruits and Vegetables

Colour is the most obvious change that occurs in many ripened fruits and is often the major criterion used by consumers to determine whether the fruit is ripe or unripe (Grierson and Kader, 1986).For the majority of fruits, the first sign of ripening is the loss of the green colour. The appearance of different colours on fruits depends on the relative amount of individual pigment present in the peel (Wills *et al.*, 1989). Colour of horticultural products fall into the following three main groups the flavonoids, carotenoids and chlorophyll.

The flavonoids are water soluble and are found mainly in the cell vacuoles of fruits and vegetables, often in the epidermal layers which include the red anthocyanins (Harborne, 1965).The chlorophyll are magnesium complexes and are green in colour. They are fat soluble (Harbone, 1965; Wills *et al.*, 1989). The carotenoids range from yellow to orange. Carotenoids are unsaturated hydrocarbons with generally forty carbon atoms and may have one or more oxy – functions in the molecules, and they are found in the chloroplast (Wills *et al.*, 1989).

The green colour of many vegetables and unripe fruit is due to the presence of chlorophyll. However, during ripening and senescence, there is a corresponding change in colour. This is attributed to the breakdown of chlorophyll. (Wills *et al*,1989). The principal causes of the breakdown of chlorophyll are pH changes mainly due to leakage of organic acids from the vacuole, oxidative system and chlorophyllases (Esteban *et al.*, 1992).

The breakdown of protopectin, a polymeric carbohydrate, weakens cell walls and the cohesive forces binding cells together. This lowers membrane integrity (Wills *et al*, 1989). This explains why there is a decrease in pH during chlorophyll breakdown at the ripening stage of most fruits. Studies have shown an increased breakdown of the protopectin when produce is stored in a normal storage environment where the oxygen concentration is not controlled. On the contrary, there was a significant retention of protopectin in product stored in modified atmosphere (Weichman, 1987). According to Alley *et al.* (1987), green beans stored in polyethylene bag maintained their green colour for 7 to 8 days and had good retailing qualities, however, green beans stored in normal storage environment, loss of the green colour was observed within the first two days of storage. It was further observed that the improved retention of the green colour in low oxygen atmosphere was due mainly to the lowering of the rate of chlorophyll breakdown.

The disappearance of chlorophyll in fruits and vegetables is associated with the synthesis of pigments ranging from yellow to red. Many of these pigments are carotenoids. Carotenoids are stable compounds and remain intact in the tissue even when extensive senescence has occurred (Harborne, 1965). He further observed that, carotenoids may be synthesized during the development stages of the plant, but they are masked by the presence of chlorophyll.

In some fruits like tomato and banana, carotenoids syntheses occur concurrently with chlorophyll degradation. After the degradation of chlorophyll, the carotenoids become visible (Esteban *et al.*, 1992). Anthocyanins, however, produce strong colour which often mask carotenoids and chlorophyll. For that matter, immature fruits may be red or purple and not green though chlorophyll and carotenoids may be present. A typical example is seen in various coloured sweet pepper fruits (Esteban *et al.*, 1992).

2.5.3 Carbohydrates in Fruits and Vegetables

The largest quantitative change associated with ripening is usually the breakdown of carbohydrate and polymers in fruits and vegetables to sugar (Wills *et al.*, 1989). These changes have the dual effects of altering the taste and texture of the produce. The increase in sugar renders the fruit much sweeter and, therefore, more acceptable (Yamaguchi, 1983).

Jobling (2001) also observed that, the rate of degradation of these carbohydrate and polymers substances is directly correlated to the rate of softening of fruits which may be a desirable characteristic if such fruits are to be used immediately. However, if the fruits are to be packed and transported to distant places or store for a longer period, softening of such fruits as a result of ripening may not be a desired quality, due to the fact that, such soft fruits become more liable to damage and injury. Raemaekers (2001) suggested that sweet pepper be harvested early enough so that they do not ripen on the plant. The breakdown of carbohydrates during ripening weakness cell walls and the cohesive forces binding cells together (Wills *et al.*, 1989).

For prolonged storage of fruits and vegetables, the breaking down of these carbohydrates should be controlled. Methods like cold storage and treatment of products with chemicals such as gibberellins have been noted to prolong storage periods of products as they reduce the breakdown of these carbohydrates (Wills *et al.*, 1989).

Another simple and common way by which fruits and vegetables are transported for longer distances and also stored for longer period, while still maintaining pre – climacteric nature, is through modified atmosphere storage. Modified atmosphere package, particularly when containing high carbon dioxide levels reduces the breakdown of pectic substance so that a firmer texture is retained (Esquerra and Bautista, 1990).

2.5.4 Water Loss from Fruits and Vegetables

Water loss from fruits and vegetables results in loss of saleable weight (Anon, 2003). Loss in weight of only 5 percent will cause many perishable commodities to appear wilted or shrivelled and under warm dry conditions, this may be evident in some produce in a few hours .Even in the absence of visible wilting, water loss can cause loss of crispness and undesirable changes in colour and palatability in some vegetables (Hayman, 1990).

Air movement over the produce is a highly significant factor influencing the rate of moisture loss. While air movement is required to remove heat from produce, its effect on moisture loss must also be considered (Jobling, 2001). There is always a thin unstirred layer of air adjacent to the surface of the produce. In this layer, the water vapour pressure is approximately in equilibrium with that of the produce itself. Air movement tends to sweep away this moist air from around the produce. Increasing the rate of air movement reduces the thickness of the boundary layer and increases the vapour pressure difference near the surface, and so increases the rate of moisture loss. Thus, restricting the air movement around the produce can effectively reduce the rate of water loss (Ben-Yoshua, 1987).

Water loss can be very effectively reduced by placing an additional physical barrier around the produce, which also reduces air movement across its surface. Simple methods are to pack the produce into bags, boxes or cartons and to cover stacks of produce with tarpaulins. Close packing of produce itself restricts the passage of air around individual items, and thus reduces water loss (Wills *et al*., 1989).

The degree to which the rate of water loss is reduced by packaging depends on the permeability of the package to water vapour transfer, as well as on the closeness of containment (Kader, 1985). All commonly used materials are permeable to water vapour to some extent. Materials such as polyethylene film are excellent vapour barriers since their rate of water transfer is low compared with that of wood, sack and fibre board which have a high permeability to water vapour. Nevertheless, even the use of fibre board, wood, sack and paper bags will substantially reduce water loss compared with unprotected, loose produce. It must, however, be remembered that packaging also reduces the rate of cooling by restricting air movement around individual items (Jobling, 2001).

From a different perspective, the ability of packaging and other materials to absorb water or water vapour can be used to achieve partial moisture control within packages. Such moisture control sinks may be utilized to lower relative humidity and avoid condensation within a package and, in turns, to reduce disorders such as fruit splitting or decay (Thompson, 1996).

Conversely, moisture sinks with sufficient absorption capacity can also work as reservoirs or moisture stores. Such moisture stores can act to return water vapour to produce what is dehydrating within a package. For example, in the case of packaged rose, dry paper packaging can be effectively used to inhibit the growth and development of grey mould. On the other hand, wrapping rose in moistened paper can effectively reduce bent neck, a disorder associated with water loss from the rose flower peduncle (Kays, 1991).

It is therefore very evident that any method which could be employed to reduce loss of moisture from stored product would go a long way to prolong the shelf–life of such products and ensure higher income for farmers. The use of modified atmosphere to reduce loss from farm products has been documented by some authors (Alley *et al.*, 1987; Hamid *et al.*, 1987). In general, leafy vegetables require a higher relative humidity level to prevent wilting. Modified atmosphere storage provides the necessary environment to reduce wilting (Alley *et al.*, 1987).

Most commonly used packaging materials in modified atmosphere storage are polyethylene and polypropylene films (Esquerra and Bautista, 1990). These materials have low permeability for gases and vapour thereby creating a relatively higher humidity in the storage environment (Fellows and Axtell, 1993).

In contrast to conditions which prevent water loss, results in wetting of stored products. This can encourages the growth of rotting organisms and in some instances cause physical splitting of the commodity (Smith *et al.*, 1988). Storage of apple in very high humidity can be a disadvantage because it could induce weight loss in cultivars susceptible to internal breakdown. It is therefore important to make holes in the films to reduce not only the build-up of vapour but also other gasses, which could be dangerous to the produce (Esquerra and Bautista, 1990).

2.5.5 Rot Caused by Pathogens

According to Thompson (1996), wastage of fruits and vegetables by micro – organism during movement from harvest to consumption can be rapid and severe, particularly in the tropical areas where high temperatures and humidity favour rapid microbial growth. He further observed that infected fruits evolved increased quantities of ethylene than the healthy ones. The ethylene produced by rotten fruit and vegetable can cause pre–mature ripening and senescence of other produce in the same storage and transport environment. Baile and Young (1981) were of the view that rotting farm produce when stored with healthy ones may cause pre-mature ripening of the healthy ones. For instance, cucumber, okro, pineapple were found to liberate 0.1 to 1.0 ppm / hour of ethylene.

However, it was found by Hayman (1990) that, the amount of ethylene produced by such produce, when rotting, tends to double or triple. The above condition therefore hastens ripening and senescence in other healthy produce kept alongside with them in the same storage or transit environment. Factors like high temperature and humidity favour the development of post harvest decay (Wills *et al*., 1989). Chilling injury also predisposes tropical and subtropical produce to post – harvest decay (Raemaekers, 2001).

In contrast, low oxygen and high carbon dioxide levels and the correct humidity as provided by modified atmosphere storage can depress the growth of pathogens (Gorini *et al.,* 1977).

The activity of several decay organisms can be reduced by atmosphere containing 10percent of carbon dioxide or more, provided that the commodity is not injured by such high carbon dioxide levels in the storage atmosphere (Wills *et al.*, 1989). Kays (1991) stated that most fruits and vegetables can be stored in atmospheres around 7 to 9 percent carbon dioxide under ambient temperature and humidity. He observed that storing the fruits in environment where carbon dioxide concentration is above 9 percent may cause defect including discolouration of the skin and pulp.

2.5.6 Mechanical Injury to Fruits and Vegetables

Injury to fruit and vegetable tissue by crushing induces ethylene evolution and substantial reduction of pre–climacteric period (Kays, 1991). Fellows and Axtell (1993) showed that although a significant decrease in pre–climacteric period occurred in response to bruises, scratches and cuts on bananas, the reduction was only of the order of 10percent which might not have a great effect during commercial storage of bananas.

Mechanical injuries inflicted on fruits by harvesting and other handling processes are noted to be one of the important factors which trigger off early deterioration of fruits and vegetables in storage (Anon, 2003).

Open wounds (eg cuts, punctures) may be inflicted on farm produce by harvesting implements. Certain injuries (bruise), however, may accumulate throughout all stages of handling including packaging and distribution (Wills *et al.,* 1989). Fruits and vegetables vary widely in their susceptibility to mechanical damage. Mechanical injuries include impact injuries, resulting from dropping the produce onto a hard surface during harvesting, packaging and other handling processes. Other forms of mechanical injury include vibration injuries, compression injuries, puncturing injuries among others (Wills *et al*., 1989).

All these injuries cause browning in the damaged tissues through oxidation of tannins. Thus, the produce would be discoloured and the market value reduced (Wills *et al.*, 1989). It was also noted by the authors that injured portions of produce are avenues for infection by micro–organisms. Mechanical injury might lead to an increase in general metabolism as the produce tries to seal off the damaged tissue. This subsequently might lead to premature ripening and senescence (Kader, 1985).

Post-harvest losses of fresh produce in less developed regions including Ghana are in part the result of mechanical injuries due to poor handling and inadequate packaging. Proper packaging of products could reduce not only bruising and crushing, but also improve marketing of produce (Anon, 2003).

One and perhaps the most important means of reducing post–harvest losses is the use of improved packaging materials and packaging techniques. The objectives of packaging are to contain, to protect, to communicate and to market product (Kader, 1985). Proper packaging will lead to reduce injuries of fruits and vegetables and subsequently improve their appearance. For instance, proper rigid packaging can reduce losses due to impact injury. Also tight fitting of packages (not overloading) can decrease the vibration of produce within the package material and consequently reduce injury (Wills *et al.*, 1989). Good packages create the necessary modified atmosphere to enhance shelf life. This was observed in tomato by Effiuvewevwere and Unwangho (1990).

CHAPTER THREE

MATERIALS AND METHODS

3.1 EXPERIMENTAL SITE

A $20m^2$ on the demonstration field of Berekum College of Education was selected and demarcated for the cultivation of the two sweet pepper varieties from 20th October, 2011 to 12th February, 2012. The site falls within the forest zone of Ghana, which has a double maxima rainfall regime, comprising a major wet season, which occurs from April to July, followed by a short dry spell in August and a wet minor season occurring from September to November (Meteorological Service Department, Berekum-Brong Ahafo, 2011).

3.2 LAND PREPARATION AND CULTURAL PRACTICES

The land size of $20m^2$ was ploughed and harrowed on 20/10/2011. Partially decomposed poultry manure (15kg) was applied on the land. The land was marked out using a tape measure, garden line, ranging poles and pegs before beds were raised. A boundary of 1.0m was marked out in the layout.

A nursery bed of 1m x 2m and a height of 20cm were raised for each variety. Seeds were nursed in drills on 29/11/2011. Germination started between 7-10 days after sowing the seeds (8/11/2011). The mulch was removed soon after seeds started sprouting, and a shed of 40cm high was raised for each bed. A week before transplanting (1/12/2011), the shed was removed to harden off seedlings. Seedlings were transplanted on 8/12/2012 in the evening. The plants were watered regularly in the evening using tap water.

Ten days after transplanting (18/12/2011), NPK 15:15:15 was applied at the rate of 5.0g per plant. The same application was applied two weeks later (1/01/2012). Pest and diseases control was done by adding 5mls of dimethoate 40 to 5 litres of water before being sprayed on the plants on 20/01/2012. Cutlass, hoe and frequent hand picking were used to control weeds on the field.

3.3 HARVESTING OF FRUITS

Physiologically mature green fruits (Yolo Wonder and California Wonder) were harvested in the evening and transported in paper cartons early in the morning to the department of Horticulture for the laboratory experiment.

3.4 SAMPLE PREPARATION

The fruits were sorted according to uniformity of size and green skin colour and those with defects or diseased were discarded. The fruits were randomly grouped into batches of ten. Fruits with uniform size, colour and no visible signs of defects were selected. A total of 300 fruits consisting of 150 fruits for Yolo Wonder and 150 fruits for California Wonder were used for the study. Ten (10) fruits of each variety were randomly selected for the four different packaging materials namely; wooden box, jute sack, low density perforated and un-perforated polyethylene bags. Two set of controls were set up for the two varieties where fruits were kept in the open (unpackaged). Diffusion holes in perforated polyethylene bags were made using a 25 gauge needle to leave thirty clean holes spaced 2cm apart. The fruits were kept under ambient temperature ranging between 29°c-30°c.

3.5 EXPERIMENTAL DESIGN

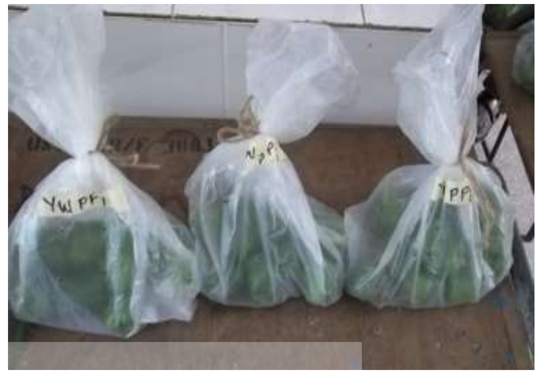
A 2x5 factorial in a Completely Randomised Design (CRD) was used. Each treatment was replicated three (3) times.

3.6 TREATMENT COMBINATION

Factor one consisted of two cultivars of sweet pepper namely Yolo Wonder and California Wonder. Factor 2 consisted of five (5) packaging materials (Wooden box, Jute sack, Low Density perforated polyethylene bags, Low Density un-perforated polyethylene bags and unpackaged fruits. The treatment combinations used included:

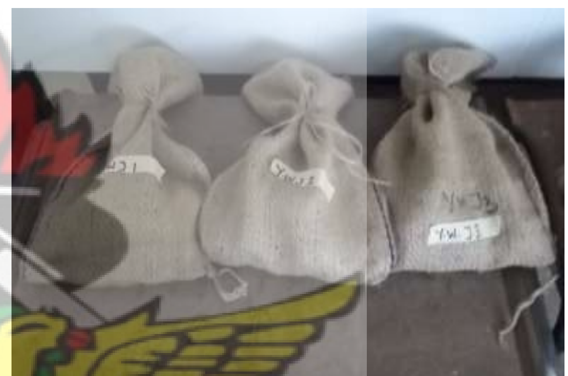
- T1 - Yolo Wonder kept in wooden box
- T2 - Yolo Wonder kept in jute sack
- T3 - Yolo Wonder kept in low density perforated polyethylene bags
- T4 - Yolo Wonder kept in low density un-perforated polyethylene bags
- T5 - Unpackaged Yolo Wonder fruits (control)
- T6 - California Wonder kept in wooden box
- T7 - California Wonder kept in jute sack
- T8 - California Wonder kept in low density perforated polyethylene bags
- T9 - California Wonder kept in low density un-perforated polyethylene bags
- T10 - Unpackaged California Wonder fruits (control)

Perforated polyethylene bag



Un-perforated polyethylene bag

Wooden box



Jute sack

Unpackaged fruits

Plate 3.1: Packaging systems used for the shelf-life studies

3.7 PARAMETERS STUDIED

3.7.1 Weight Loss

Fruits were weighed daily using an electronic balance (Sartorius Type, L-610). The loss in weight (%) of the fruits were determined using the formula

$$\text{Weight Loss (\%)} = \frac{\text{Initial Weight} - \text{Final Weight}}{\text{Initial Weight}} \text{X } 100$$

3.7.2 Fruit Firmness

Firmness (measured in Newton) of the fruits was determined using a fruit pressure tester (model F.T. 327). This was done at the twentieth day of the experiment

3.7.3 Total Soluble Solids

Total soluble solids (TSS) of fruits were determined using drops of extract on a hand held refractomete (model MT-032). Values were expressed in ^{o} brix.

3.7.4 Moisture Content

A sample of each variety was taken from each packaging material using a cork borer with a diameter 11mm. Fresh weight of each sample was recorded with electronic balance (Sartorius Type, L-610). Moisture content (%) was calculated as:

$$Moisture\ Content\ (\%) = \frac{Fresh\ weight - Dry\ weight}{Fresh\ weight} \times 100$$

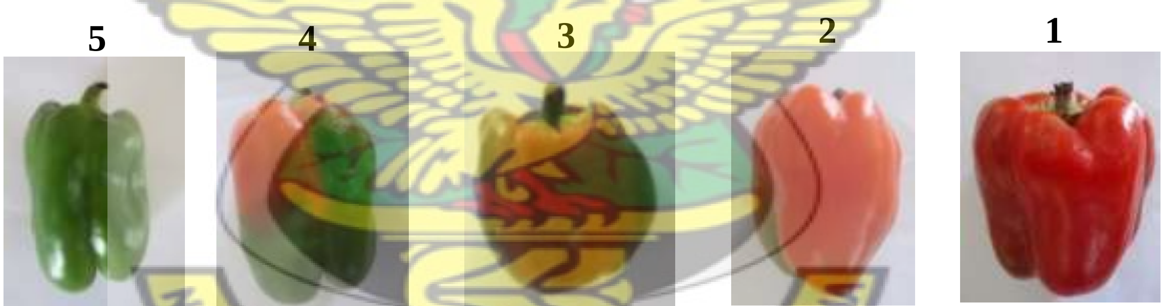
3.7.5 Dry Matter

After recording the fresh weight with an electronic balance, each sample was put into an envelop and weighed before an electronic oven was used to dry the materials at 105^{o}c for 24 hours. Dry weight (%) was calculated as the difference in fresh weight and dried weight:

$$Dry\ weight\ (\%) = \frac{Fresh\ weight - Dry\ weight}{Dry\ weight} \times 100$$

3.7.6 Fruit Colour

Fruit skin colour assessment was conducted at intervals of 5 days using a scale of 1 to 5 where 5 - uniformly green; 4 - more green than red; 3 - equally green and red; 2 - more red than green and 1 - uniformly red as shown in Plate 3.1.



Yolo Wonder Sweet Pepper Variety

California Wonder Sweet Pepper Variety

Plate 3.2: Skin Colour Assessment for Yolo and California Wonder sweet pepper variety

3.7.7 Percentage Decay Fruits

Fruits showing symptoms of rots or fungal infection were counted as decay fruit. This was express as percentage decay fruits.

$$\text{Decay Fruits (\%)} = \frac{\text{Number of decay fruits}}{\text{Total number of fruits}} \text{X } 100$$

3.7.7Percentage Shrivelled Fruits

Fruits physically showing partial to total shrinkage were counted as shrivelled fruits. This was expressed as percentage shrivelled fruits.

$$\text{Shrivelled Fruits (\%)} = \frac{\text{Number of fruits shrivelled}}{\text{Total number of fruits}} \text{X } 100$$

3.7.8 Shelf - Life Studies

Number of days taken for 50% of the sixty (60) fruits kept in each packaging material (Wooden, Jute sack, Low density Perforated and un-perforated polyethylene bags and Un-packaged fruits) to decay or lose their marketability was taken as the shelf–life of the fruit.

3.8 DATA ANALYSIS

Analysis of variance (ANOVA) was carried out at the CSIR-Crops Research Institute, Fumesua, Kumasi on the data that was obtained. Differences between treatment means were separated using Duncan's Multiple Range Test at P=0.05. A correlation analysis was performed to test the significance of association among the parameters studied.

CHAPTER FOUR

RESULTS

4.1 WEIGHT LOSS OF FRUITS (%)

Table 4.1: Weight loss of the two sweet pepper varieties

Variety	Weight loss (%)
California Wonder	48.78 b
Yolo Wonder	56.67 a

C.V. = 14.52

Values followed by the same letters are not significantly different (P<0.05)

Table 4.1 shows the weight loss of the two sweet pepper varieties. From the results, Yolo Wonder sweet pepper variety recorded the highest weight loss of 56.67% than California Wonder which had 48.78%. Significant difference (P<0.05) was observed in weight loss between the two sweet pepper varieties.

Table 4.2: Effect of different packaging systems on weight loss (%) of sweet pepper

Packaging system	Weight loss (%)
Wooden Box	73.58 a
Jute Sack	59.24 b
Un-perforated Polyethylene Bag	25.05 c
Perforated Polyethylene Bag	29.99 c
Unpackaged	75.79 a

C.V. = 14.52

Values followed by the same letters are not significantly different (P<0.05)

Table 4.2 depicts the effect of different packaging systems on weight loss of the sweet pepper fruits. Unpackaged sweet pepper fruits recorded the highest weight loss of 75.79%, followed by sweet pepper fruits packaged in wooden box (73.58%) and fruits kept in jute sacks (59.24%). Fruits kept in un-perforated polyethylene bag recorded the lowest weight loss of 25.05%. However, significant differences (P<0.05) were observed in weight loss among the various packaging systems used.

Table 4.3: Effect of variety and different packaging systems on weight loss (%)

Packaging system	Variety		Mean
	Yolo Wonder	California Wonder	
Wooden Box	77.84 a	69.33 a	73.58 a
Jute Sack	63.87 a	54.62 a	59.24 b
Un-perforated Polyethylene Bag	25.94 a	24.16 a	25.05 c
Perforated Polyethylene Bag	34.88 a	25.09 a	29.99 c
Unpackaged	80.89 a	70.68 a	75.79 a
Mean	56.69 a	48.78 b	

C.V. = 14.52

Values followed by the same letters are not significantly different (P<0.05)

Table 4.3 shows the effect of variety and the different packaging systems on weight loss of sweet pepper fruits. The results of the study showed that Yolo Wonder unpackaged fruits and fruits kept in wooden box recorded the highest weight loss of 80.89% and

77.84% respectively whiles fruits kept in both perforated and un-perforated polyethylene bags recorded the lowest weight loss of 34.88% and 25.94% respectively. For California Wonder sweet pepper, unpackaged fruits and fruits kept in wooden box also recorded the high weight loss of 70.68% and 69.33% respectively whiles fruits kept in both perforated and un-perforated polyethylene bags recorded the lowest weight loss of 25.09% and 24.16% respectively. However, no significant differences (P>0.05) were observed in weight loss among the varieties and packaging systems used.

4.2 FIRMNESS OF FRUITS

Table 4.4: Fruit firmness of the two sweet pepper varieties

Variety	Firmness (N)
California Wonder	4.89 a
Yolo Wonder	4.91 a

C.V. = 9.28

Values followed by the same letters are not significantly different (P<0.05)

Table 4.4 shows the fruit firmness of the two sweet pepper varieties. The results show that California Wonder sweet pepper variety was more firmer (4.89 N) than Yolo Wonder sweet pepper variety (4.91 N). However, no significant difference (P>0.05) was observed in fruit firmness between the two sweet pepper varieties.

Table 4.5: Effect of different packaging systems on fruit firmness

Packaging Material	Firmness (N)
Wooden Box	4.30 c
Jute Sack	4.73bc
Un-perforated Polyethylene Bag	4.53 bc
Perforated Polyethylene Bag	4.98 b
Unpackaged	5.95 a

C.V. = 9.28

Values followed by the same letters are not significantly different (P<0.05)

Table 4.5 depicts the effect of different packaging systems on fruit firmness. Fruits packaged in wooden boxes were more firmer (4.30 N), followed by fruits packaged in un-perforated polyethylene bag (4.53 N), then fruits packaged in jute sacks (4.73 N) and fruits packaged in perforated polyethylene bag (4.98 N). Unpackaged fruits were very soft and less firmer (5.95 N). However, significant differences (P<0.05) were observed in fruit firmness among the different packaging systems.

Table 4.6: Effect of variety and different packaging systems on firmness (N)

Packaging system	Variety		Mean
	Yolo Wonder	California Wonder	
Wooden Box	4.25 a	4.35 a	4.30 c
Jute Sack	4.72 a	4.74 a	4.73 bc
Un-perforated Polyethylene Bag	4.42 a	4.63 a	4.53 bc
Perforated Polyethylene Bag	5.02 a	4.94 a	4.98 b
Unpackaged	6.03 a	5.86 a	5.95 a
Mean	4.89 a	4.90 a	

C.V. = 9.28

Values followed by the same letters are not significantly different (P<0.05)

Table 4.6 shows the effect of variety and different packaging systems on fruit firmness of the sweet pepper fruits. From the results, Yolo Wonder sweet pepper, fruits kept in wooden box (4.25 N), jute sack (4.72 N) and un-perforated polyethylene bags (4.42 N) were more firmer than fruits kept in perforated polyethylene bags (5.02 N) and unpackaged fruits (6.03 N). For California Wonder sweet pepper, fruits kept in wooden box (4.35 N), jute sacks (4.74 N), un-perforated polyethylene bags (4.63 N) and perforated polyethylene bags (4.94 N) were more firmer than fruits that were not packaged (5.86 N). However, no significant differences (P>0.05) were observed in fruit firmness among the varieties and packaging systems.

4.3 TOTAL SOLUBLE SOLIDS OF FRUITS

Table 4.7: Total soluble solids (TSS) of two sweet pepper varieties

Variety	TSS (^{o}Brix)
California Wonder	5.93 b
Yolo Wonder	6.70 a

C.V. = 5.87

Values followed by the same letters are not significantly different (P<0.05)

The total soluble solids of the sweet pepper varieties are presented in Table 4.7. The results show that Yolo Wonder sweet pepper variety recorded the highest total soluble solids of 6.7 ^{o}Brix than California Wonder sweet pepper variety which recorded total soluble solids of 5.9 ^{o}Brix. Significant difference (P<0.05) was observed in total soluble solids between the two sweet pepper varieties.

Table 4.8: Effect of different packaging systems on total soluble solids (TSS)

Material	TSS (^{o}Brix)
Wooden Box	7.24 b
Jute Sack	6.63 c
Un-perforated Polyethylene Bag	3.71 e
Perforated Polyethylene Bag	5.56 d
Unpackaged	8.41 a

C.V. = 5.87

Values followed by the same letters are not significantly different (P<0.05)

The effects of the packaging systems on total soluble solids of the sweet pepper fruits are presented in Table 4.8. Unpackaged fruits recorded the highest total soluble solids of 8.4 ^{o}Brix, followed by sweet pepper fruits kept in wooden boxes (7.2 ^{o}Brix). Fruits kept in jute sacks recorded total soluble solids of 6.6 ^{o}Brix. Fruits packaged in perforated polyethylene bag recorded total soluble solids of fruit firmness of 5.6 ^{o}Brix. Un-perforated polyethylene bag had the lowest total soluble solids of 3.7 ^{o}Brix. Significant differences ($P<0.05$) were observed in total soluble solids among the different packaging systems used.

Table 4.9: Effect of variety and different packaging systems on total soluble solids

Packaging system	Variety		Mean
	Yolo Wonder	California Wonder	
Wooden Box	7.52 a	6.97 a	7.24 b
Jute Sack	7.23 a	6.03 a	6.63 c
Un-perforated Polyethylene Bag	3.72 a	3.69 a	3.71 e
Perforated Polyethylene Bag	6.13 a	5.00 a	5.56 d
Unpackaged	8.89 a	7.94 a	8.41 a
Mean	6.70 a	5.93 b	

C.V. = 5.87

Values followed by the same letters are not significantly different ($P<0.05$)

Table 4.9 shows the effect of variety and different packaging systems on total soluble solids of the sweet pepper fruits. From the results unpackaged Yolo Wonder sweet pepper fruits was high in total soluble solids (8.89 ^{o}Brix), followed by fruits kept in wooden box (7.52 ^{o}Brix), then fruits kept in jute sacks (7.23 ^{o}Brix) and fruits kept in perforated polyethylene bags (6.13 ^{o}Brix). Yolo Wonder sweet pepper fruits kept in un-perforated polyethylene bag recorded the lowest total soluble solids of 3.72 ^{o}Brix. For California Wonder sweet pepper, unpackaged fruits were high in total soluble solids (7.94 ^{o}Brix), followed by fruits kept in wooden box (6.97 ^{o}Brix), then fruits kept in jute sacks (6.03 ^{o}Brix) and fruits kept in perforated polyethylene bags (5.00 ^{o}Brix). Fruits kept in un-perforated polyethylene bag recorded the lowest total soluble solids of 3.69 ^{o}Brix. However, no significant differences (P>0.05) were observed in total soluble solids among the varieties and packaging systems.

4.4 MOISTURE CONTENT OF FRUITS

Table 4.10: Moisture content (%) of two sweet pepper varieties

Variety	Moisture Content (%)
California Wonder	92.31 a
Yolo Wonder	91.33 b

C.V. = 0.91

Values followed by the same letters are not significantly different (P<0.05)

Moisture content of the sweet pepper fruits are presented in Table 4.10. California Wonder sweet pepper variety contained more moisture (92.31%) than Yolo Wonder sweet pepper variety (91.33%). Significant difference ($P<0.05$) was observed in moisture content between the two sweet pepper varieties.

Table 4.11: Effect of different packaging systems on moisture content (%)

Packaging System	Moisture Content (%)
Wooden Box	89.76 b
Jute Sack	90.53 b
Un-perforated Polyethylene Bag	94.36 a
Perforated Polyethylene Bag	93.85 a
Unpackaged	90.61 b

C.V. = 0.91

Values followed by the same letters are not significantly different ($P<0.05$)

Table 4.11 depicts the effect of different packaging systems on moisture content of sweet pepper fruits. Sweet pepper fruits kept in un-perforated polyethylene bag recorded the highest moisture content of 94.36%, followed by fruits kept in perforated polyethylene bags (93.85%). Unpackaged fruits recorded a moisture content of 90.61% with fruits kept in jute sacks recording a moisture content of 90.53%. However, fruits kept in wooden boxes recorded the lowest moisture content of 89.76%. Significant differences ($P<0.05$) were observed in moisture content among the different packaging systems used.

Table 4.12: Effect of variety and different packaging systems on moisture content (%)

Packaging System	Variety		Mean
	Yolo Wonder	California Wonder	
Wooden Box	89.49 de	90.03 de	89.76 b
Jute Sack	89.12 e	91.93 c	90.53 b
Un-perforated Polyethylene Bag	93.50 b	95.21 a	94.36 a
Perforated Polyethylene Bag	94.11 b	93.59 b	93.85 a
Unpackaged	90.45 de	90.77 cd	90.61 b
Mean	91.33b	92.31a	

C.V. = 0.91

Values followed by the same letters are not significantly different (P<0.05)

Table 4.12 shows the effect of variety and different packaging systems on moisture content of the sweet pepper fruits. From the results, Yolo Wonder sweet pepper fruits kept in perforated polyethylene bags recorded the highest moisture content of 94.11% followed by un-perforated polyethylene bag (93.50%). Fruits kept in jute sacks recorded the lowest moisture content of 89.12%. For California Wonder sweet pepper, fruits kept in un-perforated polyethylene bags recorded the highest moisture content of 95.21%, followed by fruits kept in perforated polyethylene bags (93.59%). Fruits kept in wooden box recorded the lowest moisture content of 90.03%. Significant differences (P<0.05) were observed in moisture content among the varieties and packaging systems.

4.5 DRY WEIGHT CONTENT OF FRUITS

Table 4.13: Dry weight content of two sweet pepper varieties

Variety	Dry weight content
California Wonder	7.69 b
Yolo Wonder	8.67 a

C.V. = 10.26

Values followed by the same letters are not significantly different (P<0.05)

Table 4.13 shows the dry weight content of the two sweet pepper varieties. Yolo Wonder sweet pepper recorded the highest dry weight content of 8.67 than California Wonder which had the lowest dry weight content of 7.69. Significant difference (P<0.05) was observed in dry weight content between the sweet pepper varieties.

Table 4.14: Effect of different packaging systems on dry weight content

Packaging System	Dry matter content
Wooden Box	10.24 a
Jute Sack	9.47 a
Un-perforated Polyethylene Bag	5.64 b
Perforated Polyethylene Bag	6.15 b
Unpackaged	9.39 a

C.V. = 10.26

Values followed by the same letters are not significantly different (P<0.05)

Table 4.14 depicts the effect of different packaging systems on dry weight content of sweet pepper fruits. Sweet pepper fruits kept in wooden boxes recorded the highest dry weight content of 10.24, followed by fruits kept in jute bags (9.47). Unpackaged fruits recorded a dry weight content of 9.39 whereas fruits kept in perforated polyethylene bags recorded a dry weight content of 6.15. However, fruit kept in un-perforated polyethylene bags recorded the lowest dry weight content of 5.64. Significant differences (P<0.05) were observed in dry weight content among the different packaging systems used.

Table 4.15: Effect of variety and different packaging systems on dry weight content

Packaging system	Variety		Mean
	Yolo Wonder	California Wonder	
Wooden Box	10.51 ab	9.97 ab	10.24 a
Jute Sack	10.88 a	8.07 c	9.47 a
Un-perforated Polyethylene Bag	6.50 d	4.79 e	5.64 b
Perforated Polyethylene Bag	5.89 de	6.41 d	6.15 b
Unpackaged	9.55 ab	9.23 bc	9.39 a
Mean	8.67 a	7.69 b	

C.V. = 10.26

Values followed by the same letters are not significantly different (P<0.05)

Table 4.15 shows the effect of variety and different packaging systems on dry weight content of sweet pepper fruits. From the results, Yolo Wonder fruits kept in jute sacks had the highest dry weight content of 10.88, followed by Yolo Wonder fruits kept in wooden box which recorded the second highest dry weight content of 10.51. California Wonder fruits kept in un-perforated polyethylene bag recorded the lowest dry weight content of 4.79. Significant differences ($P<0.05$) were observed in dry matter content among the varieties and packaging systems.

4.6 FRUIT COLOUR

Table 4.16: Fruit colour of two sweet pepper varieties

Variety	Day 1	Day 5	Day 10	Day 15	Day 20
California Wonder	5 a	5 a	5 a	4 a	3 a
Yolo Wonder	5 a	5 a	5 a	4 a	3 a

C.V= 15.08

Scale: 5 - uniformly green; 4 - more green than red; 3 - equally green and red; 2 - more red than green and 1 - uniformly red

Values followed by the same letters are not significantly different ($P<0.05$)

Table 4.16 shows the fruit colour of the sweet pepper varieties. The study conducted indicated that from day 1 to day 10, both California Wonder and Yolo Wonder varieties had a colour score of 5 which meant that the fruits were uniformly green. At day 15, the fruits had a colour score of 4 meaning the fruits had more green than red. However, at day 20, the sweet pepper fruits had a colour score of 3 which meant that the fruits had equally green and red colour. No significant difference ($P>0.05$) was observed in fruit colour between the two sweet pepper varieties.

Table 4.17: Effect of different packaging systems on fruit colour of sweet pepper

Packaging System	Day 1	Day 5	Day 10	Day 15	Day 20
Wooden Box	5 a	5 a	5 a	4 a	3 a
Jute Sack	5 a	5 a	5 a	4 a	3 a
Un-perforated Polyethylene Bag	5 a	5 a	5 a	4 a	4 a
Perforated Polyethylene Bag	5 a	5 a	5 a	5 a	4 a
Unpackaged	5 a	5 a	5 a	4 a	3 a

C.V. = 15.08

Scale: 5 - uniformly green; 4 - more green than red; 3 - equally green and red; 2 - more red than green and 1 - uniformly red

Values followed by the same letters are not significantly different (P<0.05)

Table 4.17 depicts the effect of different packaging systems on fruit colour of sweet pepper fruits. The study showed that from day 1 to day 10, the different packaging systems including the control had a colour score of 5 which meant that the fruits were uniformly green. At day 15, with the exception of fruits kept in perforated polyethylene bags which had a colour score of 5, the rest of the fruits had a colour score of 4 meaning the fruits had more green than red. At day 20, the sweet pepper fruits with the exception of fruits kept in the perforated polyethylene bag which had a colour score of 4, the rest of the fruits had a colour score of 3 which meant that the fruits had equally green and red colouration. No significant differences (P>0.05) were observed in fruit colour among the Different packaging systems

Table 4.18: Effect of variety and different packaging systems on fruit colour of sweet pepper

Packaging System	DAY 1 Variety Yolo Wonder	DAY 1 Variety California Wonder	DAY 1 Mean	DAY 5 Variety Yolo Wonder	DAY 5 Variety California Wonder	DAY 5 Mean	DAY 10 Variety Yolo Wonder	DAY 10 Variety California Wonder	DAY 10 Mean	DAY 15 Variety Yolo Wonder	DAY 15 Variety California Wonder	DAY 15 Mean	DAY 20 Variety Yolo Wonder	DAY 20 Variety California Wonder	DAY 20 Mean
Wooden Box	5 a	5 a	5 a	5 a	5 a	5 a	5 a	5 a	5 a	4 a	4 a	4 a	3 a	3 a	3 a
Jute Sack	5 a	5 a	5 a	5 a	5 a	5 a	5 a	5 a	5 a	4 a	5 a	4 a	3 a	4 a	3 a
Un-perforated Polyethylene Bag	5 a	5 a	5 a	5 a	5 a	5 a	5 a	5 a	5 a	5 a	5 a	4 a	4 a	4 a	4 a
Perforated Polyethylene Bag	5 a	5 a	5 a	5 a	5 a	5 a	5 a	5 a	5 a	5 a	5 a	5 a	4 a	4 a	4 a
Unpackaged	5 a	5 a	5 a	5 a	5 a	5 a	5 a	5 a	5 a	4 a	4 a	4 a	3 a	3 a	3 a
Mean	5 a	5 a		5 a	5 a		5 a	5 a		4 a	4 a		3 a	3 a	

Scale: 5 - uniformly green; 4 - more green than red; 3 - equally green and red; 2 - more red than green and 1 - uniformly red

Values followed by the same letters are not significantly different (P<0.05)

Table 4.18 shows the effect of variety and different packaging systems on fruit colour of sweet pepper fruits. For Yolo Wonder sweet pepper varieties, the results show that from day 1 to day 10, the different packaging systems including the control had a colour score of 5 which meant that the fruits were uniformly green. At day 15, with the exception of fruits kept in perforated polyethylene bags which had a colour score of 5, the rest of the fruits had a colour score of 4 meaning the fruits had more green than red. At day 20, the sweet pepper fruits with the exception of fruits kept in perforated polyethylene bag which had a colour score of 4, the rest of the fruits had a colour score of 3 which meant that the fruits had equally green and red colouration. The same trend was seen in the California Wonder from day 1 to day 20 except for day 15 and 20 in which the colour score was 5 and 4 for fruits kept in jute sack and perforated polyethylene bag respectively. However, no significant differences (P>0.05) were observed in dry matter content among the varieties and packaging systems.

4.7 PERCENTAGE DECAY FRUITS

Table 4.19: Percentage decay fruits of the two sweet pepper varieties

Variety	Fruit Decay (%)
California Wonder	10.00 a
Yolo Wonder	10.00 a

C.V. =42.60

Values followed by the same letters are not significantly different (P<0.05)

Table 4.19 shows the percentage decay fruits of the two sweet pepper varieties. Both Yolo Wonder and California Wonder sweet pepper fruits recorded the same fruit decay of 10.00% respectively. However, no significant difference (P>0.05) was observed in percentage decay fruits among the sweet pepper varieties.

Table 4.20: Effect of different packaging systems on percentage decay fruits

Material	Decay fruits (%)
Wooden Box	0.00 c
Jute Sack	1.67 c
Un-perforated Polyethylene Bag	35.00 a
Perforated Polyethylene Bag	13.33 b
Unpackaged	0.00 c

C.V. = 42.60

Values followed by the same letters are not significantly different (P<0.05)

Table 4.20 shows the effects of packaging systems on percentage decay sweet pepper fruits. Sweet pepper fruits kept in un-perforated polyethylene bag recorded the highest percentage of decay fruits (35%), followed by sweet pepper fruits kept in perforated polyethylene bag (13.33%). However, unpackaged fruits and fruits kept in wooden box had no decay recorded. Significant differences (P<0.05) were observed in percentage decay fruits among the different packaging systems used.

Table 4.21: Effect of variety and different packaging materials on percentage decay fruits

Packaging system	Variety		
	Yolo Wonder	California Wonder	Mean
Wooden Box	0.00 a	0.00 a	0.00 c
Jute Sack	3.33 a	0.00 a	1.67 c
Un-perforated Polyethylene Bag	36.67 a	33.33 a	35.00 a
Perforated Polyethylene Bag	10.00 a	16.67 a	13.34 b
Unpackaged	0.00 a	0.00 a	0.00 c
Mean	10.00 a	10.00 a	

C.V. = 42.60

Values followed by the same letters are not significantly different (P<0.05)

Table 4.21 shows the effect of variety and different packaging systems on percentage decay fruits of sweet pepper. From the results, Yolo Wonder fruits kept in un-perforated polyethylene bags recorded the highest percentage decay fruits of 36.67% followed by fruits kept in perforated polyethylene bags (10.00%) and fruits kept in jute sacks recording 3.33% decay. Fruits kept in wooden box and unpackaged fruits had no decay fruits (0.00%). For California Wonder sweet pepper, fruits kept in un-perforated polyethylene bag recorded the highest percentage decay fruit of 33.33% followed by fruits kept in perforated polyethylene (16.67%). However, no significant differences (P>0.05) were observed in percentage decay fruits among the varieties and packaging systems.

4.8 PERCENTAGE SHRIVELLED FRUITS

Table 4.22: Percentage shrivelled fruits of the two sweet pepper varieties

Variety	Shrivelled fruit (%)
California Wonder	56.67 a
Yolo Wonder	57.33 a

C.V. = 10.52

Values followed by the same letters are not significantly different (P<0.05)

Table 4.22 shows the percentage shrivelled fruits of the two sweet pepper varieties. Yolo Wonder sweet pepper recorded the highest percentage shrivelled fruits of 57.33% than California Wonder sweet pepper variety (56.67%). No significant difference (P>0.05) was observed in percentage shrivelled fruits between the two sweet pepper varieties.

Table 4.23: Effect of different packaging systems on percentage shrivelled fruits

Material	Shrivelled fruits (%)
Wooden Box	68.33 b
Jute Sack	66.67 b
Un-perforated Polyethylene Bag	28.33 d
Perforated Polyethylene Bag	38.33 c
Unpackaged	83.33 a

C.V. = 10.52

Values followed by the same letters are not significantly different (P<0.05)

Table 4.23 shows the effects of packaging systems on percentage shrivelled sweet pepper fruits. Unpackaged sweet pepper fruits recorded the highest percentage shrivelled fruits of 83.33%, followed by sweet pepper fruits kept in wooden box (68.33%). However, fruits kept in un-perforated polyethylene bag recorded the lowest percentage shrivelled fruits (28.33%). Significant differences (P<0.05) were observed in percentage shrivelled fruits among the different packaging systems used.

Table 4.24: Effect of variety and different packaging systems on percentage shrivelled fruits

Packaging System	Variety		Mean
	Yolo Wonder	California Wonder	
Wooden Box	70.00 a	66.67 a	68.33 b
Jute Sack	66.67 a	66.67 a	66.67 b
Un-perforated Polyethylene Bag	26.67 a	30.00 a	28.33d
Perforated Polyethylene Bag	40.00 a	36.67 a	38.33c
Unpackaged	83.33 a	83.33 a	83.33a
Mean	57.33 a	56.67 a	

C.V. = 10.52

Table 4.24 shows the effect of variety and different packaging systems on percentage shrivelled of sweet pepper fruits. From the results, Yolo Wonder fruits that were not packaged recorded the highest percentage shrivelled fruits of 83.33%, followed by fruits kept in the wooden box (70.00%) and fruits kept in jute sacks (66.67%). The lowest percentage shrivelled fruits were recorded in fruits kept in un-perforated polyethylene (26.67%) and perforated polyethylene bags (40.00%). Similar observation was observed in the California Wonder sweet pepper variety where the highest percentage shrivelled fruits were recorded by the unpackaged fruits (83.33%) and the fruits kept in the wooden box (66.67%) and jute sacks (66.67%) respectively. Fruits kept in the un-perforated polyethylene (30.00%) and perforated polyethylene bags (36.67%) recorded the lowest percentage shrivelled fruits. However, no significant differences (P>0.05) were observed in percentage shrivelled fruits among the varieties and packaging systems.

4.9 SHELF - LIFE STUDIES OF SWEET PEPPER FRUITS

Table 4.25: Shelf life studies of two sweet pepper varieties

Variety	Shelf life (days)
California Wonder	11 a
Yolo Wonder	11 a

C.V. = 1.71

Values followed by the same letters are not significantly different (P<0.05)

Table 4.25 shows the shelf life studies of the two sweet pepper varieties. The sweet pepper varieties, Yolo Wonder and California Wonder had a shelf life of 11 days respectively. However, no significant difference (P>0.05) was observed in shelf life between the two sweet pepper varieties.

Table 4.26: Effect of different packaging materials on shelf-life of sweet pepper fruits

Packaging System	Shelf life (days)
Wooden Box	5 d
Jute Sack	10 c
Un-perforated Polyethylene Bag	20 a
Perforated Polyethylene Bag	15 b
Unpackaged	5 d

C.V. = 1.71

Values followed by the same letters are not significantly different (P<0.05)

The effects of the packaging systems on shelf-life of sweet pepper fruits are presented in Table 4.26. Sweet pepper fruits kept in un-perforated polyethylene bag had the longest shelf-life of 20 days, followed by fruits kept in perforated polyethylene bag (15 days) and fruits kept in jute sacks (10 days). Unpackaged sweet pepper fruits and fruits kept in wooden box had the shortest shelf-life of 5 days. Significant differences (P<0.05) were observed in shelf-life among the different packaging systems used.

Table 4.27: Effect of variety and different packaging systems on Shelf-life

Packaging System	Variety		Mean
	Yolo Wonder	California Wonder	
Wooden Box	5 a	5 a	5 d
Jute Sack	10 a	10 a	10 c
Un-perforated Polyethylene Bag	20 a	20 a	20 c
Perforated Polyethylene Bag	15 a	15 a	15 b
Unpackaged	5 a	5 a	5 d
Mean	11 a	11 a	

C.V. = 1.71

Values followed by the same letters are not significantly different (P<0.05)

Table 4.27 shows the effect of variety and different packaging systems on shelf life studies of sweet pepper fruits. The results shows that Yolo Wonder fruits kept in un-perforated polyethylene bag recorded the longest shelf life of 20 days, followed by fruits kept in perforated polyethylene bags (15 days) with fruits kept in jute sacks having a shelf life of 10 days. Fruits kept in wooden box and unpackaged fruits recorded the shortest shelf life of 5 days. .The same trend was observed in the California Wonder sweet pepper variety. However, no significant differences (P>0.05) were observed in shelf life studies among the varieties and packaging systems.

Table 4.28: Regression analysis for shelf-life of sweet pepper fruits

Variables	Means + S.E.	P-value
Constant	22.75 ±2.52	0.000
Percentage rotten fruits	0.12 ± 0.04	0.009
Total Soluble Solids (TSS)	-1.06 ± 0.40	0.015
Percentage wrinkled fruits	-0.12 ± 0.03	0.001
R - square (r^2)	0.93	
Adjusted R square	0.92	
Number of observation	30	

The regression analysis shows that about 92% of variations or changes observed in the shelf-life of the sweet pepper fruits can be explained by changes in percentage rotten fruits, total soluble solids and percentage shrivelled fruits (Table 4.28).

4.10 CORRELATION MATRIX FOR PARAMETERS STUDIED

Table 4.29 tested the association among the parameters studied. From the results, dry matter had a significant negative correlation with moisture content (-1.00). Total soluble solids (TSS) had a significant positive correlation with dry matter (0.78) and firmness (0.46) but a significant negative correlation with moisture content (-0.78). Percentage wrinkled fruits had a significant positive correlation with dry matter (0.78) and total soluble solids (0.87) but had a negative correlation with moisture content (-0.78). Percentage rotten fruits had significantly positive correlation with moisture content (0.78) but negative correlation with dry matter (-0.78), total soluble solids (-0.85) and percentage wrinkled fruits (-0.83). Shelf-life on the other hand had significant positive correlation with moisture content (0.82) and percentage rotten fruits (0.90) but negative correlation with dry matter (-0.82), firmness (-0.28), total soluble solids (-0.92) and percentage wrinkled fruits (-0.92).

Table 4.29: Correlation matrix for parameters studied

	Weight loss	Moisture content	Dry matter	Firmness	TSS	% Shrivelled fruits	% decay fruits
Moisture content	0.01						
Dry matter	-.001	-1.00**					
Firmness	-0.04	-0.13	0.13				
Total Soluble Solids (TSS)	-0.06	-0.78**	0.78**	0.46**			
% Shrivelled fruits	-0.23	-0.78**	0.78**	0.33	0.87**		
% Decay fruits	-0.02	0.78**	-0.78**	-0.24	-0.85**	-0.83**	
Shelf life	0.16	0.82**	-0.82**	-0.28	-0.92**	-0.92**	0.90**

** - significant at 1% (P=0.01); * - significant at 5% (p=0.05)

CHAPTER FIVE

DISCUSSION

5.1 WEIGHT LOSS OF FRUITS

The study conducted showed that Yolo Wonder sweet pepper stored for 20 days lost more weight than the California Wonder variety. The differences observed in between the two sweet pepper variety can be attributed to varietal differences that exist between Yolo Wonder and California Wonder sweet pepper. Also fruits packaged in perforated and un-perforated polyethylene bags had lower weight loss. The sweet pepper fruits kept in these packaging systems maintained their quality better than the rest of the package systems used because they had the best appearance. According to Aharoni *et al*. (2007) plastic film materials are known to reduce water loss during prolonged storage. The reduction in water loss observed in the polyethylene bags plays a key role by serving as a tight barrier to water evaporation. This explains why fruits kept unpackaged and those kept in wooden boxes lost high amount of water because they offered less resistance to water loss.

Also the low weight loss observed in the polyethylene bags could be attributed to the slowed physiological processes such as respiration and transpiration that occur in the bags (Kays, 1991).The high weight loss seen in the unpackaged fruits as well as the fruits packaged in boxes could be attributed to the increase rates of respiration and other metabolic processes that could have contributed to the depletion of substrates sugar and proteins resulting into further weight loss (Buescher, 1979).

Zoran *et al*. (2012) working on heat treatment and individually shrink packaging material on bell pepper fruit stored at suboptimal temperature reported that shrink-wrapped bell pepper fruits had low rate of weight loss and the best fruit quality. They further indicated that unwrapped fruit recorded higher weight loss and shrivelling as was seen in the current study.

Jobling (2001) reported that air movement over the produce is a highly significant factor influencing the rate of moisture loss. While air movement is required to remove heat from produce, air movement tends to sweep away the thin moist air from around the produce. According to Ben-Yoshua (1987), increasing the rate of air movement over the produce surface, reduces the thickness of moist air layer thereby increasing the vapour pressure difference near the surface leading to increased rate of moisture loss.

Kader (1985) argued that the degree to which the rate of water loss is reduced by packaging depends on the permeability of the package to water vapour transfer, as well as on the closeness of containment. Jobling (2001) added that materials such as polyethylene film are excellent vapour barriers since their rate of water transfer is low compared with that of wood, sack and fibre board which have a high permeability to water vapour. Thus, restricting the air movement around the produce can effectively reduce the rate of water loss.

5.2 FRUIT FIRMNESS

Fruit firmness between Yolo Wonder and California Wonder did not differ from one another. This may be due to the fact that the two sweet pepper varieties have the same fruit characteristics, hence no significant difference seen in their firmness. In the packaging systems used, fruit softening was delayed in sweet pepper fruits kept in the packaging systems than those unpackaged. Fruits kept in the packaging systems were found to be firmer than those left in the open. Fruits kept in the un-perforated polyethylene bags were also firmer than those kept in the perforated bags. The unpackaged fruits were softer after 20 days in storage because of the amount of water loss from the fruits. Sweet pepper fruits are known to have thicker pericarp tissues and high skin wax and therefore serve as a good water reservoir and most probably contribute to fruit firmness. Meir *et al.*, (1995) and Gonzalez-Aguilar *et al*., (2000) reported that film packaging was effective in reducing quality loss of bell peppers as they prevent moisture loss from the fruit. Lurie *et al*., (1986) in their research found that a strong relationship between fruit firmness and weight loss in bell pepper. According to Bustan and Lahav (2010) the application of natural beeswax emulsion on sweet pepper extended shelf-life by 3-6 days after 21 days of storage and maintaining 70% of the fruit marketable firmness levels. Also Showalter (1973) working on pepper firmness reported that a pronounced decreased in fruit firmness was associated with increased weight loss for fruits stored in plastic bags.

5.3 TOTAL SOLUBLE SOLIDS OF FRUITS

In terms of total soluble solids, the Yolo Wonder sweet pepper variety was sweeter than the California Wonder variety since the Yolo Wonder variety was high in total soluble solids than the other. For the packaging systems used, the high total soluble solids recorded in the unpackaged fruits and fruits kept in wooden boxes and jute sacks coincided with the ripening colour stages 3 of the sweet pepper fruits. This can be explained by the fact that as the fruit ripens more of its cell walls and structures are degraded to provide energy for its respiratory activities. Esteban *et al.*(1992) observed that during ripening and senescence, there is an increase fruit activity which is characterized by an increased usage of fruit sugar.

In the same way, the lower TSS values recorded by un-perforated polyethylene bags suggest that respiratory activities in the fruits were slower than in the unpackaged fruits, hence, a little amount of sugars available in the fruits. This can be explained by the fact that the increased usage of the sugars in respiration followed by increased reduction of fruit quality as the fruits become ripe. According to Esquerra and Bautista (1990) reducing carbon dioxide and water vapour to the tolerant levels in most storage environment contribute significantly to maintaining high TSS.

5.4 MOISTURE AND DRY WEIGHT CONTENT OF FRUITS

Relatively, the California Wonder sweet pepper variety had more moisture compared to the Yolo Wonder. This is due to the fact that the Yolo Wonder variety loss more weight than the California Wonder, hence the differences observed in the moisture content of the fruits. The reverse was however observed in the dry weight content of the fruits. It can be inferred that Yolo Wonder sweet pepper variety which loss more weight and moisture, had more dry matter content than the California Wonder sweet pepper variety. The differences observed in the varieties in terms of moisture loss and dry weight content can therefore be attributable to varietal differences existing between the two.

For the packaging systems used, sweet pepper fruits kept in polyethylene bags had high moisture content than fruits kept in the open or in jute sacks or in wooden boxes. The high moisture levels recorded could be due to the fact that the polyethylene bags did not allow enough water loss from the fruits compared to the other packaging systems. The unpackaged fruits, jute sack and wooden box offered low protection to the fruits and therefore allowed rapid water loss from the fruits to the surrounding air as was reported by Jobling (2001) that the air movement over the produce was a highly significant factor in determining the rate of moisture loss.

However, the dry weight of the sweet pepper fruits had effect on moisture content. Fruits kept in polyethylene bags recorded the lowest dry matter content than the other packaging materials. This can be attributed to the fact that the polyethylene material did not allow rapid moisture loss from the fruits which affected the dry matter content. On the other hand fruits kept in the wooden box which loss more moisture had more dry weight content.

5.5 FRUIT COLOUR

In terms of fruit colour, the two sweet pepper varieties exhibited the same trend in ripening from day 1 to day 20, changing from uniformly green to half green and half red fruits. The ripening pattern seen in the two varieties Yolo Wonder and California Wonder can therefore be said to be the same. The different packaging systems used also exhibited the same ripening pattern except for polyethylene bags which still retain more green skin colour of fruits. Similar work done by Nyanjage *et al*., (2005) indicated that packaging does not significantly affect colour retention. It can be inferred that the perforated polyethylene material did allow gaseous exchange between the fruits and the environment better even though it regulated the amount of water lost by the fruit; hence, better retention of green colour of the sweet pepper fruits. According to Grierson and Kader(1986) and Nyalala and Wainwright (1998), the loss in green colour of the sweet pepper could probably be attributed to the increased breakdown of chlorophyll and synthesis of b-carotene and lycopene pigments, which occur during ripening. Kays (1991) pointed out that low respiration activity of sweet pepper fruits lowers their rate of ripening and deterioration, hence the high retention of green colour observed.

5.6 FRUIT DECAY

Fruit decay was not significantly different between the varieties. Decay recorded was the same for both Yolo Wonder and California Wonder sweet pepper varieties. The susceptibility of the fruits to decay organisms may be due to other environmental factors beside the varieties ability to resist rot. For the packaging systems, fruits kept in un-perforated polyethylene bags had more decay than fruits kept in the perforated polyethylene bags and the jute sacks. The un-perforated polyethylene material inhibited fruit senescence by reducing water loss which leads to the accumulation of moisture in and around the produce. This condition created favours microbial development, hence the percentage decay recorded. No decay recorded in the unpackaged fruits and fruits kept in wooden boxes could be attributed to the fact that those packaging materials allowed proper air circulation thereby reducing the amount of moisture accumulated on the fruit surface, hence creating an unfavourable environment for growth of decay pathogens. Coates *et al*., (1995) reported that high disease incidence observed with un-perforated packaging could be due to the accumulation of high relative humidity and water condensing around the produce, which promote the development of decay organisms as was seen in the current study.

5.7 SHRIVELLED FRUITS

The Yolo Wonder sweet pepper variety showed more shrivelled fruits than the California Wonder sweet pepper variety. The differences could be attributed to the fact that the Yolo Wonder fruits loss more weight and retained less moisture than the California Wonder variety, hence the higher number of shrivelled fruits recorded by Yolo Wonder. For the packaging systems used, fruits kept in the open (unpackaged) had more shrivelled fruits than fruits kept in some form of packaging systems. This can be explained by the fact that as water evaporates from the tissues, turgor pressure decreases and the cells begin to shrink and collapse thus leading to loss of freshness or market quality. Wills *et al*., (1998) attributed the high water loss from the fruits to air movement, which tends to sweep away the unstirred layer of air adjacent to the surface of the produce thus increasing the vapour pressure deficit. Maalekuu *et al*., (2005) reported high weight loss and shrivelling unwrapped fruit where water stress was found to contribute to fruit senescence. Packaging materials such as wooden boxes and jute sacks do not provide an efficient barrier against moisture loss from the fruit tissues, hence the higher percentage of shrivelled fruits recorded. Both the perforated and un-perforated polyethylene bags retain fruit freshness and had less shrivelled fruits since the confinement of moisture around the produce in the bag increased the relative humidity and therefore reduced the vapour pressure deficit and transpiration. Thompson (1996) reported that polyethylene material created a modified atmosphere with higher concentration of carbon dioxide and reduced oxygen around the produce, which slows down the metabolic processes and transpiration.

5.8 SHELF - LIFE STUDIES OF FRUITS

In terms of the shelf life studies conducted, the sweet pepper varieties; Yolo Wonder and California Wonder had the same short shelf life of 11 days. This is attributed to the fact that sweet pepper is a very perishable vegetable with a short shelf-life. Hence the short shelf life can also be due to the inherent postharvest problems associated with the fruits. For the packaging systems used, sweet pepper fruits kept in the un-perforated polyethylene bag stayed longer (20 days) than fruits kept in perforated polyethylene bag (15 days) and jute sacks (10 days). This is because the fruits kept in the polyethylene bags loss less moisture and therefore look fresher. This observation can be explained by the fact that the polyethylene material served as a barrier to moisture loss resulting in the quality of the sweet pepper fruits and the low percentage shrivelled fruits recorded. Meir *et al*., (1995) reported that using plastic materials such as polyethylene bag packaging was a useful in maintaining the postharvest quality of the pepper fruits as it prevents water loss and fruit softening.

The short shelf-life experienced in the unpackaged fruits and fruits kept in the wooden box can be attributed to rapid moisture loss from the fruit resulting in loss of quality accompanied by the high percentage shrivelled fruits recorded. According to Bayoumi (2008) sweet pepper is a very perishable vegetable with a short shelf-life. He attributed the inherent postharvest problems of the fruits after harvesting to metabolic and physiological activities, quality degradation and shrivelling, as well as fast physical decay and rapid senescence.

Ceponis *et al*., (1987) reported that the storage life of pepper fruit was limited by pathological deterioration. Diaz-Perez *et al*., (2007) also in their shelf life studies concluded that rapid water loss was a major determinant of fruit shelf life. Kader (2002) recommended rapid cooling of fruits after harvest and storage at optimum temperature of 7–10^{o}C with a high relative humidity of 95–98% help extend the shelf life of most fruits.

CHAPTER SIX

SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

6.1 SUMMARY OF FINDINGS

An experiment was conducted to assess the effect of packaging materials on quality and shelf-life of sweet pepper fruits at the Laboratory of the Department of Horticulture, KNUST, Kumasi.

From the study, California Wonder sweet pepper variety had the lower weight loss (48.78%) than the Yolo Wonder variety. Also both perforated and un-perforated polyethylene bags recorded the lowest weight loss of 29.99% and 25.05% respectively. In terms of fruit firmness, the packaging materials were firmer than the unpackaged fruits. However, fruit packaged in perforated polyethylene bags recorded lower fruit firmness than those kept in un-perforated polyethylene bags.

Yolo Wonder sweet pepper variety had higher total soluble solids (6.7^{o}Brix) than the California Wonder variety. For the packaging materials used, unpackaged fruits had the highest total soluble solids of 8.41^{o}Brix with fruits kept in wooden box recording 7.24^{o}Brix.

The California Wonder had higher moisture content of 92.1% than the Yolo Wonder (91.33%). Sweet pepper fruits kept in un-perforated and perforated polyethylene bags had high moisture content of 94.36% and 93.85% respectively.

For dry weight, Yolo Wonder fruits recorded higher dry weight (8.67) than California Wonder (7.69). For the package materials, wooden box had the highest dry weight of 10.24 than jute sack (9.47) and unpackaged fruits (9.39).

At the end of the storage period, the polyethylene material (un-perforated and perforated) retained the green skin colour of the sweet pepper (score 4) better than the wooden box, jute sacks and the unpackaged fruits. It also recorded more decay fruits (35% and 13%) but few shrivelled fruits (28.33% and 38.33%) and finally recorded the longest shelf-life of 20 days and 15 days respectively.

6.2 CONCLUSIONS

Sweet pepper is an important fresh vegetable used in a variety of dishes in Ghana but deteriorates rapidly during handling and storage due to poor post-harvest handling leading to huge losses. The current study had shown that using the right packaging material coupled with proper handling, the quality and shelf-life of the two sweet pepper varieties could be improved.

In conclusion, using unperforated low density polyethylene bags for storing both sweet pepper varieties extended shelf-life and maintained better appearance as such fruits were less shrivelled.

6.3 RECOMMENDATIONS

Based on the findings from the work conducted, the following recommendations are made.

1. For longer shelf-life and quality, keeping fruits in unperforated polyethylene bags should not be extended beyond the twentieth day as majority of the fruits started decaying.
2. Further studies should be conducted using different densities of polyethylene materials and postharvest treatments in improving quality and extending shelf-life of the sweet pepper fruits

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APPEENDIX

Analysis of Variance Table for Weight Loss

Source	DF	SS	MS	F	P
VARIETY	1	469.1	469.06	8.00	0.0104
PACKAGE	4	13752.7	3438.17	58.64	0.0000
VARIETY*PACKAGE	4	72.8	18.21	0.31	0.8675
Error	20	1172.7	58.64		
Total	29	15467.3			

Grand Mean 52.731 CV 14.52

Analysis of Variance Table for Fruit Firmness

Source	DF	SS	MS	F	P
variety	1	0.0016	0.00161	0.01	0.9305
package	4	9.7747	2.44366	11.82	0.0000
variety*package	4	0.1349	0.03371	0.16	0.9546
Error	20	4.1349	0.20674		
Total	29	14.0460			

Grand Mean 4.8973 CV 9.28

Analysis of Variance Table for Total Soluble Solids (TSS)

Source	DF	SS	MS	F	P
variety	1	4.4699	4.4699	32.58	0.0000
package	4	76.4070	19.1018	139.23	0.0000
variety*package	4	1.3994	0.3498	2.55	0.0710
Error	20	2.7440	0.1372		
Total	29	85.0203			

Grand Mean 6.3120 CV 5.87

Analysis of Variance Table for Moisture Content

Source	DF	SS	MS	F	P
variety	1	7.164	7.1639	10.18	0.0046
package	4	107.528	26.8820	38.20	0.0000
variety*package	4	10.166	2.5414	3.61	0.0226
Error	20	14.076	0.7038		
Total	29	138.933			

Grand Mean 91.820 CV 0.91

Analysis of Variance Table for Dry Matter Content

Source	DF	SS	MS	F	P
variety	1	7.164	7.1639	10.18	0.0046
package	4	107.528	26.8820	38.20	0.0000
variety*package	4	10.166	2.5414	3.61	0.0226
Error	20	14.076	0.7038		
Total	29	138.933			

Grand Mean 8.1800   CV 10.26

Analysis of Variance Table for Fruit Colour

Analysis of Variance Table for COLOUR DAY 1

Source	DF	SS	MS	F	P
rep	2	6.163E-30	3.081E-30		
variety	1	1.158E-31	1.158E-31	2.7E+31	0.0000
package	4	6.549E-30	1.637E-30	3.8E+32	0.0000
variety*package	4	1.809E-63	4.522E-64	0.10	0.9797
Error	18	7.830E-62	4.350E-63		
Total	29	1.283E-29			

Grand Mean 5.0000

Analysis of Variance Table for COLOUR DAY 5

Source	DF	SS	MS	F	P
rep	2	6.163E-30	3.081E-30		
variety	1	1.158E-31	1.158E-31	2.7E+31	0.0000
package	4	6.549E-30	1.637E-30	3.8E+32	0.0000
variety*package	4	1.809E-63	4.522E-64	0.10	0.9797
Error	18	7.830E-62	4.350E-63		
Total	29	1.283E-29			

Grand Mean 5.0000

Analysis of Variance Table for COLOUR DAY 10

Source	DF	SS	MS	F	P
rep	2	5.686E-30	2.843E-30		
variety	1	0.03333	0.03333	0.30	0.5906
package	4	0.53333	0.13333	1.20	0.3449
variety*package	4	0.13333	0.03333	0.30	0.8741
Error	18	2.00000	0.11111		
Total	29	2.70000			

Grand Mean 4.9000 CV 6.80

Analysis of Variance Table for COLOUR DAY 15

Source	DF	SS	MS	F	P
rep	2	0.2000	0.10000		
variety	1	0.3000	0.30000	0.84	0.3729
package	4	2.4667	0.61667	1.72	0.1902
variety*package	4	0.8667	0.21667	0.60	0.6653
Error	18	6.4667	0.35926		
Total	29	10.3000			

Grand Mean 4.3000 CV 13.94

Analysis of Variance Table for COLOUR DAY 20

Source	DF	SS	MS	F	P
rep	2	0.60000	0.30000		
variety	1	0.53333	0.53333	2.03	0.1715
package	4	2.86667	0.71667	2.73	0.0620
variety*package	4	0.46667	0.11667	0.44	0.7755
Error	18	4.73333	0.26296		
Total	29	9.20000			

Grand Mean 3.4000 CV 15.08

Analysis of Variance Table for Decay Fruits

Source	DF	SS	MS	F	P
REP	2	140.000	70.0000		
VARIETY	1	1.972E-29	1.972E-29	0.00	1.0000
PACKAGE	4	5433.33	1358.33	74.85	0.0000
VARIETY*PACKAGE	4	100.000	25.0000	1.38	0.2811
Error	18	326.667	18.1481		
Total	29	6000.00			

Grand Mean 10.000   CV 42.60

Analysis of Variance Table for Decay Fruits (Transformed data)

Source	DF	SS	MS	F	P
REP	2	3.478	1.7389		
VARIETY	1	0.007	0.0066	0.01	0.9159
PACKAGE	4	126.171	31.5427	54.56	0.0000
VARIETY*PACKAGE	4	3.614	0.9034	1.56	0.2270
Error	18	10.406	0.5781		
Total	29	143.675			

Grand Mean 2.3897   CV 31.82

Analysis of Variance Table for Shrivelled Fruits

Source	DF	SS	MS	F	P
REP	2	20.0	10.00		
VARIETY	1	3.3	3.33	0.09	0.7642
PACKAGE	4	12513.3	3128.33	87.08	0.0000
VARIETY*PACKAGE	4	46.7	11.67	0.32	0.8577
Error	18	646.7	35.93		
Total	29	13230.0			

Grand Mean 57.000 CV 10.52

Analysis of Variance Table for Shrivelled Fruits (Transformed data)

Source	DF	SS	MS	F	P
REP	2	0.0678	0.0339		
VARIETY	1	0.0059	0.0059	0.04	0.8507
PACKAGE	4	60.1840	15.0460	92.37	0.0000
VARIETY*PACKAGE	4	0.3323	0.0831	0.51	0.7291
Error	18	2.9319	0.1629		
Total	29	63.5219			

Grand Mean 7.4419 CV 5.42

Analysis of Variance Table for shelf-life

Source	DF	SS	MS	F	P
REP	2	5.40	2.700		
VARIETY	1	0.03	0.033	1.00	0.3306
PACKAGE	4	1008.13	252.033	7561.00	0.0000
VARIETY*PACKAGE	4	0.13	0.033	1.00	0.4332
Error	18	0.60	0.033		
Total	29	1014.30			

Grand Mean 10.700 CV 1.71